The impact of Science Literacy delivery methods - what works?

Summary Report

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Executive Summary

The basis for commissioning the research project *The impact of Science Literacy delivery methods - what works?* in late 2017 was the emergence of a variety of branches of Science Literacy or semi-independent 'issue literacies' – perhaps most prominently Health Literacy - over the last two decades. The research aimed to bring together what is already known about the effects of approaches and methods, to examine good practice in impact evaluation methodology, and to identify any major gaps and future needs. In this final stage, a summary and synthesis of the results from the earlier stages has been carried out, accompanied by an effort to model in outline the 'toolkits' needed by organisations conducting projects which develop and execute an Impact Assessment plan. The research has been structured under 7 Groups of delivery mechanisms (representing 45 individual mechanisms). Detailed results and a statistical breakdown for each Group and mechanism can be found at the study website.

The study has covered both formal education and non-formal/informal education through the programmes of many different types of institutions. Health literacy (HL) endeavours form an important part of the findings. The number of documented Impact Assessment activities relevant to Science Literacy discovered globally, going back to the 1990s, was much greater than forecast at the outset, exceeding 2,000 items in the English language.

The major outputs of the study include: a comprehensive (but non-exclusive) bibliographic organisation of material, with source links; analysis of strengths, weaknesses and gaps for individual mechanisms; a significant effort towards the development of an ontological framework for analysing the implementation of Impact Assessments and suggestions on toolkits/IA frameworks covering each Group of mechanisms, provided in a separate *Outline Model Toolkit Framework* linked to this Summary.

In this Summary it is not possible to reflect all of these findings in any depth or with evenly distributed coverage. However, an overview is provided based on some of the mechanisms with the greatest volume of recent interests. It is noteworthy that the 'digital shift' in progress since the millennium has intensified and is reflected by the heightened interest shown in assessing the impact of e-learning and online interactions overall. The issues covered in the Summary are grouped, respectively as: Extending audience reach through Events; Curricula; e-Learning; Visualisation; Makerspaces; Online interactions and Multiple Literacies. A section on Impact Evaluation as a discipline, introduces its definition, development and some of its main elements as a taster for greater elaboration in the accompanying *Outline Model Toolkit Framework*.

In conclusion, the outcomes of the global work covered by the study provide a more than sufficient demonstration of how a palette of implementation practice, documented and disseminated widely, can strengthen emulation first in clusters and then, more widely, adaptation to different circumstances to achieve change and improvement in science communication, globally.

Although substantial work has already been done, much remains to be achieved in understanding the profound effects (both positive and negative) of digital technologies such as e-learning, social media, mobile apps and web-based services on improving Science Literacy in both formal and non-formal settings. The COVID-19 pandemic has necessitated a hastening of the uptake of online modalities, the impact of which-- in the longer term--is undetermined. Tantalising questions remain to be addressed about the extent to which the well-managed adoption of digital technologies lead to beneficial transformations in knowledge, attitudes and behaviour in a field such as Science Literacy, despite the undoubtedness of their impact on increasing the ease and volume of communication. These appear to be a priority at present and a recommendation emerging from this work is that they should be pursued at greater scale and more systematically in the near future.

A great deal of informative IA in Science Literacy has been carried out in relatively small-scale settings. Nevertheless, it is noteworthy that quite often - and especially in a digital context – this can lead to demands for bigger 'proofs' and more widely relevant evidence. In view of the multiplicity of types of agency engaged in the delivery of science and ancillary issue literacies, and the consequent fragmentation of resources and approaches, the time may be ripe for a process of convening and a consolidation of effort which can lead to a standardisation of tooling in the wider interests of science communication.

1. Introduction - The research and its results

The basis for commissioning the research project *The impact of Science Literacy delivery methods - what works?* in late 2017 was the emergence of a variety of branches of Science Literacy or semi-independent 'issue literacies' – perhaps most prominently Health Literacy - over the last two decades, leading to experimentation and innovation with numerous different approaches and mechanisms for their delivery.

The research has been carried out by the Network for Information and Digital Access (NIDA), with financial support of the Evergreen Education Foundation (EEF) and NIDA (2017 -2020) and a contribution from Hardie Wren Development Initiatives (2018). The research aimed to bring together what is already known about the effects of approaches and methods, to examine good practice in impact evaluation methodology and to identify any major gaps and future needs. In this final stage, a summary and synthesis of the results from the earlier stages has been carried out, accompanied by an effort to model in outline the 'toolkits' needed by organisations conducting projects which develop and execute an Impact Assessment plan, indicating any major variations which may be needed in the contexts of different delivery mechanisms.

The research has been structured under 7 Groups of delivery mechanisms (representing 45 individual mechanisms). Detailed results for each Group and mechanism can be found at the study website.

The Groups are:

1. Events, Meetings, Performances;
2. Education and Training, including online;
3. Traditional Publishing and Journalism, print and broadcast;
4. Activities and Services;
5. Online Interactions ;
6. Multiliteracies, Multimodalities; and
7. Citizen Science.

The study has covered both formal education and non-formal/informal education through the programmes of many different types of institutions. Health literacy (HL) endeavours form an important part of the findings, not least because of the relative prevalence of interventions in this field, and consequent assessment of their impact. In general, relevant findings about HL are integrated in the main text of the summary.

A very substantial amount of work has been involved in resource discovery, review, assessment and organisation of the results. The number of documented Impact Assessment activities relevant to Science Literacy discovered globally, going back to the 1990s, was much greater than forecast at the outset. 1,005 such resources were identified during the resource discovery process, which lasted until March 2019, along with 1,132 'secondary' resources (such as reviews, guides, handbooks, reports etc.). Documents and articles were retrieved from a wide range of sources, including research databases, Google Scholar, ResearchGate, subject databases, open access repositories etc. The retrieval was restricted to those in the English language. A statistical breakdown of the resources reviewed, according to delivery mechanism and group is provided on the study website. For one of the seven Groups, Citizen Science, it was not possible to identify financial resources required to analyse the work as far as hoped, although a substantial bibliographic compilation was completed.

In general, during the course of the study, it has become necessary, in the light of available resources, to take an adaptive approach toward the original workplan and objectives. Certain goals e.g. the possible identification of selective field trials proved unnecessary or impractical in the context of the large amount of existing information discovered.

Some aspects of the work undertaken, such as the production of Working Papers for selected individual mechanisms and the compilation of published reviews are focused on the period 2013-18. During this period, the 'digital shift', in progress since the millennium, intensified and is reflected by the heightened interest shown in assessing the impact of e-learning and online interactions overall.

The major outputs of the study include:

- a comprehensive (but non-exclusive) bibliographic organisation of material, with links for online access where available, according to delivery mechanism. Existing published guidance and toolkits have been consolidated, which helps inform the basis for the suggestions on toolkits/IA frameworks covering each Group of mechanisms, provided in a separate document linked to this Summary.
- strengths, weaknesses and gaps for individual mechanisms (based on a review of the literature until 2018) have been analysed are detailed in tabular form;
- significant effort towards the development of an ontological framework for analysing the implementation of Impact Assessments, which may have scope for continued development. The development of this framework is mainly reflected in the Working Papers which have been compiled for seven of the Delivery mechanisms, but also maintained in the database underpinning the research. More detail is provided later in this summary document for those that may be a worthwhile area for refinement and further work.

Behind this, the study has been supported by ongoing release of progress reports and promotion of results to communities, institutions and agencies of all kinds, together with discussion and interaction with a wide range of interested and engaged parties, locally and globally.

2. Science Literacy delivery mechanisms: strengths, weaknesses and gaps

The following is an overview based on some of the mechanisms with the greatest volume of recent interests. These findings can be analysed as mainly concerning aspects which broadly concern Learning Opportunities and Learning Outcomes, respectively. Identified weaknesses for individual mechanisms are shown in *italics*, gaps and future needs in **bold.**

2.1 Extending audience reach through Events

Some SL delivery mechanisms are better at reaching audiences that may feel alienated from traditional settings.

Several Group 1 (G1) events-based mechanisms fall into this category. *However, in* <u>Exhibitions</u>*, learning may be determined by the teacher or science-communication venue staff, not by the student. Although students enjoy free exploration, it can create frustration and little learning-related behaviour*. There is significant evidence that interactive science exhibitions increase visitors' knowledge and understanding of science and that Science and Discovery Centres provide memorable learning experiences which can have a lasting impact on attitudes and behaviour, wide-ranging personal and social impacts, and promote inter-generational learning. There is also evidence that they promote trust and understanding between the public and the scientific community and have economic impact. *The interception of* <u>Festivals</u> *audiences depends on the location of the venue, time of the year and duration of the festival. They also require intensive volunteer participation by scientists, universities, technologists and engineers*. *For* <u>Science Fairs</u>*, time constraints and time-management are significant factors. They need adequate preparation and guidance, requiring organisational abilities and volunteer time, especially from teachers. They may trigger anxiety among students and there might be communication barriers (e.g. for deaf students). Materials and resources required for scientific experimentation can be expensive and may aggravate economic discrepancies between schools and individual students*. <u>Workshops</u> *require contents, materials and vocabulary to be tailored to the audience in order to trigger changes, which might require other empowerment approaches. The time required to implement contents can be resource-demanding, especially for attendees.*

Creative activities such as <u>Theatre</u> (G1) performances stimulate imagination and thinking and encourage curiosity, reducing the gap between cognitive and creative learning, with communication based on emotions. Performances can be introduced into traditional STEM (Science, Technology, Engineering and Maths) education to become STEAM (STEM + Art) and can be low cost activities (e.g. puppet shows). *There is potential for misinterpretation of the performance resulting from artistic or aesthetic objectives: isolated performances might work better if embedded within programmes.*

2.2 Curricula

Curriculum (G2) integration of science and technology with other school subjects can be a way to teach it within the constraints of an overloaded curriculum and may compensate at relatively low cost for primary teachers' lack of confidence in science teaching. Sufficient complexity in the form of integration improves the prospects for gains in learning outcomes. *However, the more complex the type of curriculum integration is, the higher the required investment.*

2.3 e-Learning

The potential advantages of e-Learning *(*G2) are widely stressed, in terms of access in a diversity of settings, student control of pacing, personalisation, content updating, lower cost and presentation within a blended learning context. E-Learning, including Webinars (G2), can improve access to higher education for people from numerous backgrounds and situations, offering an alternative method of education. The relevance of this has become even more evident during the COVID pandemic, which began after the completion of the research. Web-based learning allows ideas to be presented in a variety of ways using multimedia components, such as mobile learning, MOOCS and digital badges in agriculture.

On-line learning activities (e.g. experiments) and interactive visual and verbal communication can be useful in low literacy settings. Some findings demonstrated that student learning outcome achievement is equal or higher in non-traditional, remote laboratories when compared with traditional research laboratories, across all learning outcome categories (knowledge and understanding, inquiry skills, practical skills, perception, analytical skills, and social and scientific communication).

Others found little statistical difference between groups in e-learning and traditional learning relating, for example, to nurses' or student nurses' knowledge, skills and satisfaction. Scientific inquiry skills have been among the least assessed learning objectives and laboratory reports/written assignments and practical exams the least common assessment instrument. In agriculture*, a*ctive learning e.g. through small-scale vegetable gardens and community farms and rooftop farms in urban areas, is often effective.

Potential disadvantages and inequalities which have arisen in what is an ongoing development process include: costs related to technology and in developing programmes, possible technical problems, limited direct interaction, lack of exchanges and relations with other learners, absence of the physical presence of the teacher, decrease in motivation to learn, need for greater self-discipline, attenuation of the desire to compete with other learners, poor access, language barriers and lack of computer and Internet literacy limiting participation and leading to higher dropout rates than for face to face learning. e-Learning poses problems for students' academic integrity (i.e. fraud and cheating) and can intensify the digital divides. The nature of the Internet provides no global safeguards for reliability of material or the protection of data against misuse. Webinars (G2) *may suffer from lack of personalisation. Increased levels of anxiety when using computers has been noted. Lack of skills associated with ICT can impact the learning progress of students who can also be frustrated by unreliable university computer systems, lack of technical support and the amount of time wasted when computer applications do not work as expected. Educators might need to improve their own ICT skill base and may need extra support during course development outside of the normal teaching workload, requiring the use of incentives to motivate those not currently adopting e-learning teaching strategies.*

Sufficient data, breadth of focus and improved methodologies are needed to make impact assessment of e-learning relevant and effective. Robust quantitative instruments are needed to measure the impact, effectiveness and perceptions of students and educators, research going beyond the 'does it work' question instead to determine what influences its effectiveness (e.g. interactivity, immersion, critical features).

2.4 Visualisation

Rich experiences that are often not found in a traditional classroom setting can provide skills that students need in the twenty first century. Animations (G3) can facilitate the understanding of graphical representation, abstract concepts and changes across time or space, and provide active approaches to learning research methods and statistics. Meta-analysis has reviewed the effect of animation on learning. Overall a positive effect of animation was found in multimedia material, especially when learning with iconic visualizations. Learning was enhanced with animation when no accompanying text was provided. **There is a necessity to better describe visualizations in papers, whether static or animated.** Games (G3) provide learners with opportunities to collaborate, problem-solve, and to develop a sense of place in a simulated world through self-discovery. Games based Learning (GBL) is a potentially engaging form of supplementary learning. Elements of video games could be used to improve classroom-based science education. Learning occurs naturally while playing games: they can enhance learning by connecting game worlds and real worlds, providing effective virtual environments for science learning, in which players can become absorbed and engaged in the embedded science learning activities. Playing good video games in itself is a process of thinking and learning. *Despite this, games require a lot of resources (e.g. a multidisciplinary team, substantial expertise, creativity, time, and funding) and gameplay must be supported with appropriate feedback and scaffolding.*

There is little or inconclusive evidence that games can promote development of scientific skills, understanding of science content or an understanding of the nature of science. There is a need for longitudinal studies to show whether games maintain their impact over time. Evaluation of student learning outcomes is still limited to knowledge acquisition, although game designs were guided by different theories or models to provide a variety of learning opportunities. A clearer definition of effectiveness for D(Digital)GBL needs to be formulated, together with a common methodology for assessing their effectiveness and motivation, more RCTs, evaluation of the long-term effects of games in health promotion, and seeing games as cultural tools for science education rather than potential replacements for science instruction.

A heavier focus is needed on accurate and reliable assessment of higher order learning outcomes, weighing the benefits of experimental designs in the light of specific requirements of research questions under exploration, analysing the relationships between in-game performance, game playing experience, gaming behaviours, and science learning outcomes to validate student learning assumptions.

Cartoons (G3) based on everyday situations enable students lacking in confidence to be less intimidated by the science and more likely to engage with it and are effective across geographical and cultural boundaries. They encourage learners to explore alternative ideas and can be a very effective way to challenge misconceptions, acting as an effective stimulus enabling students to co-construct arguments. They can help comprehension and communication in health care, especially in low literacy settings.

Comics (G3) can be a visually interactive and innovative educational tool, appealing to a wider audience across all age and ethnic groups because they employ everyday language, combining the benefits of visualization with powerful metaphors and character driven narratives to make scientific subjects more accessible and engaging, providing the basis for emotional attachment and self-reference, addressing sensitive subjects, and mapping abstract scientific concepts on to everyday objects and experiences. They are low cost, easily portable and potentially a useful tool for education in a public health crisis.

2.5 Concise formats

There is a role for concise overviews of SL topics, which may often be supplemented by informal, informed discussion between the presenter and audience and can promote active learning.

During the period covered by the research, Television (G3) was still the most popular source of information on health and illness, and constitutes an important source of education in terms of prevention and avoiding risk behaviours, accessible and present in a wide spectrum of formats reaching a vast and diversified group of viewers. *However, broadcast messages may not focus on the content but the mere fact of making it public. Recipients also need to be aware when series are fiction features and do not aim to faithfully reflect reality, and that therefore the information needs to be treated with caution. Television messages can be of* *low quality and of insufficient factual level when referring to health topics*. ICT expansion and streamed content has increased audiences' ease of access to entertainment narratives such as feature films and border-free TV productions. Such narratives can be effective in health campaigns in countries or areas where traditional text-based literacy is limited but *may convey both negative and positive messages*.

At a simpler level, *Posters* (G3) were found to be beneficial to conference organisers, authors and delegates, relatively inexpensive to produce and provide the audience with information that can be viewed by a number of individuals at their own pace. In all settings, the graphical design and physical appearance of the poster can determine its success in promoting knowledge transfer. *However, posters are not well equipped to accommodate alternative learning styles and need to provide clear navigation in order to provide a sequential logic if not accompanied by an active intervention (e.g. oral presentation, physical interaction). The 'traditional' poster may only reach a limited proportion of its intended audience and are quite expensive in terms of the person-hours, publishing costs and travel expenses.*

2.6 Makerspaces

Makerspaces (G4) can increase community engagement with STEM knowledge and have potential in advancing interest in STEM careers. They foster the development and demonstration of 21st century skills, such as problem solving, critical and creative thinking, collaboration, and communication. Public, academic and industry libraries retain a valuable role in nurturing critical thinking skills in local and research communities, providing knowledge of and access to key agricultural databases, collecting and preserving indigenous knowledge. *However, the benefits might not be evenly available. Resource constraints can be challenging for makerspaces and libraries both in developed and developing countries.*

Formal methods and techniques are needed to assess the outcomes, including empirical research evaluating makerspaces and making, of makerspaces and learning. Many challenges still exist in finding ways to measure the impact of informal learning environments. Current tools do not capture the complex interdisciplinary learning taking place in makerspaces, making demands for new forms of assessment. Improvements in the formalised approach to outcomes assessment could bring greater validity and reliability to the techniques being used, including clearly articulated objectives or intended outcomes, appropriate techniques and instruments, consistent approaches, scheduled frequency of assessment, and reporting. Learner-centred assessment according to learners' individual goals and variations in learning among students are challenging but provide opportunities for peer teaching and models of shared leadership.

2.7 Online interactions

Mobile Apps (G5) have achieved wide reach and become increasingly prevalent among users, particularly suited to population groups who may be more accepting of technology, including children and young people. They are low cost, constantly available, easily updatable with current information, provide access to assistance, and are enormously scalable because of the private use of cell phones, offering more active engagement that can potentially impact health behaviours and monitoring globally. Once again, the COVID-19 pandemic is providing significant opportunities to further test these findings.

Some identified downsides and constraints include unstable Wi-Fi or Internet connections, slow data processing, short battery life, and small screen size: mobile phone technology might be challenging particularly for elderly users. Ensuring confidentiality and privacy can be a common concern (e.g. how sensitive and personal data are handled, transmitted and stored).

The persistent and compulsive nature of self-monitoring tools warrant particular caution. Being unable to adhere to a monitoring routine may contribute to feelings of shame and guilt, which could reduce control users have over the ways they interact with interventions. There is a risk that researchers are developing apps primarily for research needs, rather than to meet the needs of end users. There further remains a lack of innovative pedagogical guidelines on how best to use mobile devices to improve academic processes and achievements.

Rigorous research is needed to test the effectiveness and acceptability, use and content, methodologies, scope and context of mobile apps. This may require comprehensive evaluation to date of public and commercial apps, and high quality research on their effectiveness (most studies are small scale and for a short period only). Qualitative results are based on self-reports and perceptions of using different types of mobile devices.

There is a lack of similarity in study designs (choice of outcome measures, sample size) in this area, increasing the difficulty of drawing conclusions about effectiveness in promoting behaviours (e.g. reduced cancer risk), requiring evidence from RCTs and longitudinal studies. Evidence is needed for the efficacy of mental health, smoking cessation and safety apps, as well as evidence to support the mental health safety of apps with vulnerable populations. Large-sample, high quality, adequately powered RCTs and longitudinal studies are required. Intervention studies should consider the inclusion of both a control arm and an app-only arm to make the link clearer between the app and the outcome, build stronger evidence bases for the efficacy of mobile apps in health, and investigate across more varied science topics and diverse audiences, including agriculture. Comparisons are needed with other mHealth interventions such as text messaging and emails.

Cost-effective communication tools can empower listeners with health information and create social networks for information sharing. <u>Podcasts (G5)</u> used in the education sector require less literacy than text-based resources, and little technological expertise to produce. They are easy to share via social media, websites and email, and can be accessed on mobile devices while doing other activities but *can be time-consuming*. They may be particularly good vehicles for emotional intimacy and disclosure. **Further investigation is needed of their efficacy as tools for teaching of knowledge in practical subjects and higher education.**

<u>Social media</u> (G5) are informal, dynamic, social and flexible environments where more or less structured learning experiences can take place, facilitating interplay between formal education and real life, bridging personal experiences and institutional knowledge, and allowing for personalisation of the content, presentation and participation, at low cost. Their collaborative nature allows for a meaningful contribution and interaction from all user groups and peer/social/emotional support. Their high-reach dissemination potential can be used by healthcare professionals to improve translation of evidence-based health information to health consumers and patients, with potential to influence health policy. Social networks in agriculture can support cooperatives, collaborations and peer learning across borders.

People with limited access to the Internet and few social networks may be at a disadvantage. The acceptability of social media interventions might be a problem in terms of cultural dimensions and norms. Quality concerns and lack of reliability, confidentiality, and privacy may be an issue for certain populations such as older adults. Inappropriate substitution of online information and misinformation are risks that can potentially lead to harmful results, often due to limited capacity for self-regulation and vulnerability to peer influence. There is potential information overload for the user and there may be limitations on the ability of health care professionals to form relationships with social media users in comparison to face-to-face interaction. Developing new social media platforms may be costly or resource intensive. The use of Facebook and other prominent international social media brands requires digital and media literacy skills in order to face the cognitive and ethical issues.

Future research on social media should aim to investigate which interventions are effective and describe all aspects of the interventions, how they are implemented and utilised. They should:

- **engage with existing social networks, acceptability and use of social media and assess both desirable and undesirable effects, explicitly documenting any increased negative behaviours, stigmatisation or exacerbation of existing inequalities (e.g. in health) if some populations are excluded;**
- **collect and analyse the effect of interventions by different population groups;**
- **in health literacy specifically (but by extension in other target fields too) clarify whether the use of social media truly confers an advantage, or if the novelty of the medium is solely responsible for its use;**

- **trial with larger sample sizes and more robust methodologies to fully determine the role of social media for health communication, health promotion, in supporting the patient- health professional relationship and clinically significant behaviour change;**
- **create designs to investigate how the particular affordances of social media are best suited to addressing different user or patient needs;**
- **focus on robust and comprehensive evaluation and review, using a range of methodologies, to determine the impact of social media for communication in specific population groups with large sample sizes and (representation) using RCTs and longitudinal studies to determine the longer-term impact;**
- **explore potential mechanisms for monitoring and enhancing the quality and reliability of health communication using social media;**
- **investigate the risks arising from sharing information online and the consequences for confidentiality and privacy, determining the impact of peer-to-peer support to enhance interpersonal communication;**
- **explore the potential for social media to lead to behaviour change for healthy lifestyles to inform health communication practice; and**
- **take into account how cultural differences between countries affect the propensity to adopt international social media products for learning and the ways students react to their use in education according to different cultural variables (e.g. religion, ethnic identity) adopting suitable learning design approaches.**

Wikis (G5) are friendly spaces, where users can easily locate, create, edit, and share information) with great potential as an instructional strategy to aid students in learning various skills (e.g. improving writing performance), gaining and constructing new knowledge, and allowing learners to interact and connect with each other within virtual learning environments where they can appreciate divergent views and demonstrate team-based skills, linking and connecting individuals, complementing and improving online peer collaboration. Collaborative writing applications (CWAs) (e.g. wikis and Google Documents) can improve the use of evidence in both public health and health care and positively affect the education and knowledge translation of health professionals. *However, collaboration does not occur easily or without guidance. There are issues related to safety, reliability of information, lack of traditional authorship and impartial editing, and legal implications for decision making regarding the use of CWAs in some sectors*.

Wikis require further trials with objective outcomes, given that the majority of the literature presently exists in the form of case reports with self-reported measurements, identifying implementation processes that can be influenced by collaborative writing applications (CWAs) and how to measure them (possibly using Web metrics) as intermediate outcomes of a complex knowledge translation intervention. Exploration is needed on the impact of collaborative writing and conversational features on information sharing, investigating what kind of knowledge (explicit vs tacit) is shared. This could help knowledge users choose an appropriate CWA. As future communication tools, the impact of using different types of media embedded within CWAs (audio and video recordings) should also be explored. More research is needed to determine which stakeholders benefit the most from using CWAs, to address the barriers to their use, to find ways to ensure the quality of their content, to foster contributions, and to make these effective knowledge translation tools for different stakeholders. There is a need to conduct systematic reviews to further synthesize the results of experimental and quasi-experimental studies in the field of health professionals' education, and to further synthesize evidence about implementation strategies addressing the different barriers identified. Future research in nursing education is needed and should focus on the design of wiki-based writing and the amount of structure that should be provided to encourage variation and creativity. Another area of potential research is finding the best strategies to help students feel comfortable and confident to edit not only their own work but also that of their peers and move from the role of reader to writer and editor.

2.8 Multiple literacies and multiple modalities

Today's learner is expected to be 'multiliterate', i.e. able to integrate creativity, think independently, collaborate, present diverse views, think and communicate in new ways, and analyse and construct meaning from information through a variety of media and circumstances. Educational programmes underpinned by **multiliteracy** (G6) 'pedagogy' supported by technology can provide meaningful learning experiences for students while achieving focused learning outcomes. **Important factors such as teachers' technology competencies and expertise, access and integration of technology, effective learning scaffolds, inquiry-based and collaborative experiences, need to be addressed.**

Multimodal opportunities to learn, teach and present ideas are particularly useful for meeting specific educational needs, for example, individuals with low literacy levels, and for communicating abstract concepts that may be challenging to demonstrate in classrooms. Videos (G3) have offered paced viewing to support the learner and demonstrate potential as an affordable and flexible tool for agricultural extension, farmer-to-farmer exchange and health literacy. With other media, such as TV, Radio, newspaper columns, etc., they are effective for training and providing information to illiterate farmers. *Weaknesses include infrastructural constraints, i.e. the reliance on power and connectivity, affordable access to the internet, mobile/smartphone ownership, and opportunity for use, particularly in rural and resource-deprived contexts. Their effectiveness can also depend on additional instructional scaffolding around the intervention (e.g. instructor facilitation, materials and participant activities). Reach is dependent on physical location and timing in order to enable inclusive participation (e.g. greater involvement of females in rural areas)*

3. Impact and its evaluation

There are various definitions of Impact. In its framework for international development, the OECD describes impact as, "Positive and negative primary and secondary long-term effects produced by an intervention, whether directly or indirectly, intended or unintended."

The terms Impact Evaluation (IE) and Impact Assessment (IA) are sometimes used interchangeably, and it may not be possible to avoid such terminological overlaps. In this summary, IE is used to describe a specific type and purpose (a 'discipline') within the general field of evaluation, and an IA used to describe specific cases or instances with a defined methodology.

IE has strong roots in the fields of medicine and health involving the principles of comparison, under controlled conditions and statistical analysis of the possibility of error. Drawing on the work of Archibald Cochrane in the 1960s and 70s, Randomised Controlled Trials (RCT) involving control groups, randomization, and blinding are seen as the core methodology in assessing clinical therapies. However, RCT are far from straightforward. Reflecting a more general trend toward evidence-based policies, research and practice, interest in IE has spread to many fields in education, science, social science and humanities. In these contexts, an 'intervention' might therefore be a small project, a large programme, a collection of activities, or a policy.

Impacts are usually understood to occur later than, and as a result of, intermediate *outcomes*. For example, achieving the intermediate outcomes, say, of improved access to land and increased levels of participation in community decision-making might occur before, and contribute to, the intended final impact of improved health and well-being for women. However, the distinction between outcomes and impacts can be relative, depending on the stated objectives of an intervention. Some impacts may be 'emergent' as things proceed, and thus, cannot be predicted.

Evaluation, by definition, answers questions about quality and value. This is what makes evaluation more useful and relevant than simply measuring indicators or summarising observations and stories. IE can have formative, summative, advocacy-oriented, and other purposes. In any impact assessment, it is important to define first what is meant by 'success' (e.g. quality, value). This can lead to defining specific evaluation criteria with different levels of performance (or standards), deciding what evidence will be gathered, and how it will be synthesized to reach defensible conclusions. Those defined by OECD-DAC include: Relevance, Effectiveness, Efficiency, Impact and Sustainability.

Evaluation relies on a combination of facts and values to judge the merit of an intervention. Like any other evaluation, an impact evaluation should be planned formally and managed as a discrete project, with decision-making processes and management arrangements clearly described from the beginning of the process. Participatory approaches are often favoured, raising the question: who should be involved and why? Purpose, objectives and target audience help determine the need for rigour, methodology (and cost).

IA frequently assess changes in KAB: knowledge, attitudes, behaviours. A 'theory of change' may explain at the outset how activities are understood to produce a series of results that will contribute to achieving the ultimate intended impacts. This can continue to be revised over the course of evaluation should either the intervention itself or the understanding of how it works change. The IA might confirm the theory of change or it may suggest refinements based on the analysis of evidence. Failure to achieve the final intended impacts might be due to theory failure rather than implementation failure. A Theory of Change is, however, helpful in guiding causal attribution in an Impact Assessment.

Determining causal attribution: a*scription of a causal link between observed (or expected to be observed) changes and a specific intervention* is often seen as requirement for calling an activity Impact Evaluation, and the challenges of this are a major issue in IE. It is not, however, necessary that changes are produced solely or wholly by the intervention under investigation and it is understood that other causes or contextual factors may also be taken into account ('external' or 'extraneous' factors'), for example prior knowledge, motivation, and interest.

There are many different methods for collecting and analysing data in IE. The credibility of evaluation findings can be increased when information from different data sources converge to deepen the understanding of the effects and context of an intervention, making use of different question types and considering different research design options. These different approaches are important when deciding what will be considered credible by the intended user of the evaluation or by partners or funders. Designing valid Impact Assessments with acceptable results involves a substantial range of technical and interpretive considerations

The extent and sophistication of impact assessment in the science literacy field, its academic documentation, and evident momentum over two decades, exceeded the expectations held by the study team at the outset of the work. Impact assessment methodologies in Science Literacy emulate those apparent in other fields. A temporary tendency to prefer qualitative data in some institutional contexts over 'hard' quantitative data has in more recent years often been supplanted by a preference for 'mixed-method' approaches, and in turn for calls for wider focus, larger samples, greater longitudinality and sometimes efforts to implement RCTs. However, resource constraints remain a significant factor in this direction.

A more detailed elaboration of these issues is provided in the *Outline Model Toolkit Framework*, which accompanies this Summary.

4. Conclusion

The research carried out in this study has brought together and organised a vast amount of English-language documentation on Impact Evaluation in the field of Science Literacy and related 'issue literacies' such as in health and agriculture. This included both records of individual Impact Assessment (IA) implementations and relevant overviews and guidance, going back 25 years or more, but gathering pace and quantity since the last turn of the century.

This material has been analysed in a number of different ways to try to determine important strengths, weaknesses and gaps both in the means ('mechanisms') of delivering Science Literacy and in the ways their impact is assessed. To enable this, a structure was developed which grouped known mechanisms together into 7 categories. This structure has also been used in considering what tools may be appropriate for consideration in conducting IA, provided in a separate, but linked *Outline Model Toolkit Framework* document. Carrying out these analyses also provided a context for systematising somewhat the elements for consideration in implementing Impact Assessments and thereby establish the basis of an 'ontological framework', which may have scope for continued development.

The main limitations of the study pertain to the unexpectedly large body of research discovered across the very wide range of defined delivery mechanisms which, in view of the inevitably restricted financial, personnel and temporal resources available, has circumscribed the depth and type of analyses possible. Nevertheless, an important corpus of information has been collected and organised, which should enable others to pursue research on specific aspects more readily.

The outcomes of the global work covered by the study provide a more than sufficient demonstration of how a palette of implementation practice, documented and disseminated widely, can strengthen emulation first in clusters and then, more widely, adaptation to different circumstances to achieve change and improvement in science communication, in both developed and developing countries.

The 'digital shift' of the 21st century and the massive adoption of new technologies has created a critical new context for Impact Evaluation in Science Literacy, as in other fields. Although substantial work has already been done, much remains to be achieved in understanding the profound effects (both positive and negative) of digital technologies such as e-learning, social media, mobile apps and web-based services on improving Science Literacy in both formal and non-formal settings. The COVID-19 pandemic has necessitated a hastening of the uptake of online modalities, the impact of which in the longer term is undetermined. Tantalising questions remain to be addressed about the extent to which the well-managed adoption of digital technologies leads to beneficial transformations in knowledge, attitudes and behaviour in a field such as Science Literacy, despite the undoubtedness of their impact on increasing the ease and volume of communication. These appear to be a priority at present and a recommendation emerging from this work is that they should be pursued at greater scale and more systematically in the near future.

A great deal of informative IA in Science Literacy has been carried out in relatively small-scale settings. Nevertheless, it is noteworthy that quite often--and especially in a digital context--this can lead to demands for bigger 'proofs' and more widely relevant evidence, so that proposals for methodological improvement to impact assessment frequently relate to: increasing longitudinality, directness and use of data in measurement; experimental designs, bigger and more random samples and triangulation of methods to increase validity; better quantification of different types of learning; matching materials and narratives which may help determine specific literacies to specific audiences and which may rely on different cognitive mechanisms.

In view of the multiplicity of types of agency engaged in the delivery of Science and ancillary issue literacies and the consequent fragmentation of resources and approaches, the time may be ripe for a process of convening and a consolidation of effort which can lead to a standardisation of tooling in the wider interests of Science Communication.

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